RELATED ASYMMETRIES IN ACHILLES TENDON STIFFNESS AND ANKLE MOBILITY AFTER RUPTURE

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INTRODUCTION

The Achilles tendon is one of the largest and strongest in the body, yet is most prone to unilateral spontaneous rupture in humans. This injury dramatically changes the tissue's composition, which has a significant effect on its mechanical behavior [1] and presumably on ankle joint function. Earlier work has considered this particular relationship between the mechanical status and function of the Achilles tendon after post-rupture healing and attempted tissue regeneration. However, these were either limited to animal models [2] or indirect parameters of tendon stiffness, namely passive biomechanics of the plantarflexors [3]. Loss of plantarflexor muscle strength after Achilles tendon rupture has already been well documented [4], but the *in vivo* status of the regenerated tendon tissue has yet to be elucidated in human subjects. Thus the relationship between tendon stiffness and post-rupture ankle function may be an indicator of tissue regenerative status. We hypothesize that subjects with higher asymmetries in tendon stiffness will demonstrate similarly higher asymmetries in ankle mobility during gait.

METHODS

Sixteen subjects (3 female, 13 male, Age: 45.4 ± 13) were recruited 2-5 years following minimally invasive surgery of an Achilles tendon rupture performed by the same surgeon (SM). Self-reported patient satisfaction was determined for each patient by taking a variety of different clinical scores at the time of biomechanical evaluation: Achilles Tendon Rupture Scores (ATRS), American Orthopaedic Foot and Ankle Society (AOFAS), Trillat, and Thermann Scores.

Kinematic data of the lower limbs were collected (f=120Hz) using a set of 22 reflective markers and 10 infrared cameras (VICON, Oxford, UK) for a minimum of five barefoot walking trials at a self-selected speed. ISB-recommended conventions were used to determine ankle angles [5].

Elastic properties of the Achilles tendon (elongation, strain, and stiffness) were determined for both injured and contralateral sides using both dynamometry to record the ankle moment (Biodex, NY, USA) and ultrasonography to determine the displacement of the musculo-tendinous junction during five maximal voluntary plantarflexion efforts [6].

Relative asymmetry was determined by taking the ratio of injured to contralateral parameters. Pearson's 1-tailed test was used for correlations. All data were processed within the MATLAB suite (Mathworks, MA, USA) and statistical analysis in SPSS (IBM, NY, USA).

RESULTS AND DISCUSSION

All subjective clinical scores showed high patient satisfaction across multiple tests 2-5 years following surgical intervention and healing. The results from the AOFAS (91.3 ± 9.3) and the ATRS (86.6 ± 11.2) yielded "good" to "very good" outcomes. The Trillat functional scores found that four patients (25%) had "very good" outcomes, nine patients (56%) with "good", and three patients (19%) with "satisfactory". Thermann scores showed that two patients (13%) had very good outcomes, eight patients (50%) had good outcomes, five patients (31%) had moderate outcomes, and one patient (6%) had fair outcomes.

Ankle range of motion (ROM) was limited on the injured side in the flexion-extension (30.3° vs. 33.0°, p <0.05) axis. Representative kinematic data from a single patient (Figure 1) show that the injured side has limited plantarflexion during the swing phase of gait, and that the overall mobility of the ankle is smaller compared to the contralateral side.s (Figure 1). Tendon stiffness was significantly higher in the injured side compared to the contralateral side (207.9 vs. 94.7 N/m, p<0.05). Tendon elongation (10.1 vs. 17.0 mm) and strain (4.8 vs. 8.7%) were lower on the injured tendon (both p<0.05).

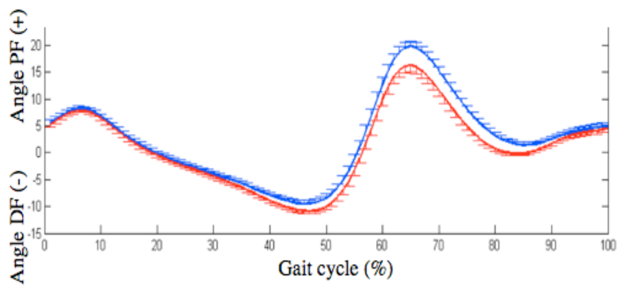

Figure 1: Flexion-extension ankle angles (in degrees) for the injured (red) and contralateral sides during a single gait cycle across all patients. Error bars show the standard error of the mean for all trials at 1% intervals of the gait cycle.

All of the tendon elastic properties were significantly different between the injured and contralateral sides (Table 1). Tendon stiffness was significantly higher in the injured side compared to the contralateral side. Both tendon elongation and strain were significantly lower on the injured tendon (both p<0.05).

Table 1: Achilles tendon elastic properties as measured by ultrasonography. All p-values are from a paired comparison.

Parameter	Injured	Contralateral	p-value
Tendon stiffness (N/m)	201.5 ± 96.7	97.1 ± 51.4	0.034*
Tendon elongation (mm)	10.1 ± 2.7	17.0 ± 4.0	0.001*
Tendon strain (%)	4.78% ± 1.42	8.67% ± 2.03	0.001*

Correlation of the kinematic versus stiffness asymmetries with a Pearson's rho test yielded a negative correlation of -0.0623 with r=0.62 (*p(1-tailed)*=0.005).

This study shows that even after 2-5 years after tendon rupture, significant functional deficits were present in all patients. Additionally, these were mirrored by a lack of tissue elasticity on the affected side. However, correlation analysis of the two factors demonstrated that tendon stiffness accounted for only a portion of the deficit in ankle mobility. It is likely that a number of external factors contribute to limited ankle mobility during gait. One potential point of future investigation could be neuromuscular, to see if there are changed patterns of muscle activation in the lower extremity during active movement.

An important point to consider is that these biomechanical deficits were not evident in the various clinical evaluations of the patients. This discrepancy suggests that patient-reported scores may not be indicative of the biomechanical status of the ankle joint and healed Achilles tendon. The combination of these biomechanical tests could be implemented to more precisely evaluate the relative efficacy and efficiency of various tissue engineering and regenerative therapies.

CONCLUSIONS

Lasting asymmetries in elastic properties within the post-rupture Achilles tendon appear to be related to the functional range of motion displayed by the ankle joint during active movement. It is suggested that these parameters could be used to determine the relative efficacy of therapeutic interventions for enhancing Achilles tendon regeneration.

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REFERENCES

1. Voleti PB, et al., *Annu Rev Biomed Eng*. **14**:47-71, 2012.
2. Best T, et al. *J Ortho Res*, **11(6)**:897-906, 1993.
3. Don R, et al., *Clin Biomech*, **22**: 211-220, 2007.
4. Mullaney M, et al., *Am J Sports Med*, **34(7)**:1120-5.
5. Wu G, et al., *J Biomech*. **35(4)**:543-548, 2002.
6. Arampatzis A, et al., *J Biomech*. **38**: 833-41, 2005.